REPORT

OF THE

Committee of the Franklin Institute,

ON

Dynamo-Electric Machines

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REPORT OF THE COMMITTEE

ON

Dynamo-Electric Machines.

The Board of Managers of the Franklin Institute having empowered its Committee on Instruction to purchase a Dynamo-Electric Machine, it was deemed advisable to examine into the merits of, and to test, the various machines offered for sale. This was undertaken partly as a guide in making a selection for purchase, and also to obtain reliable data regarding the adaptability of such machines to the production of Light.

In view of the scientific importance of the work, the Committee on Instruction, which consists of five members of the Board of Managers, availed themselves of the services of four other members of the same, who, by request, assisted in the investigation, and now join in this report.

The work was divided among Sub-Committees as follows:

On Photometric Measurements, Messrs. Briggs, Profs. Rogers and Chase. On Electric Measurements, Profs. Houston, Thomson, and Mr. Rand. (Mr. Rand's business engagements prevented his taking active part in the work of this sub-committee.) On Dynamical Measurements, Messrs. Jones, Sartain and Knight.

Previous to the commencement of the labors of the Committee, an invitation was extended to makers of dynamo-electric machines, with a request that they should furnish machines for competitive trial. This invitation was also given in the columns of the JOURNAL of the Institute, and received general publication in the newspapers and scientific periodicals. Especial requests were addressed to M. Breguet, of Paris, France, maker of the "Gramme" machine; to Messrs. Sie-

mens Bros., of London, Eng., makers of the "Siemens" machine; to Messrs. Condit, Hanson & Van Winkle, of Newark, N. J., makers of the "Weston" machine; to the Telegraph Supply Co., of Cleveland, Ohio, makers of the "Brush" machine; and to Messrs. Wallace & Sons, of Ansonia, Conn., makers of the "Wallace-Farmer" machine.

The only machines supplied directly from the makers were two each of the Brush and Wallace-Farmer types, but the Committee were gratified in obtaining, through the courtesy of Prof. H. W. Wiley, of Purdue University, Lafayette, Ind., a "Gramme" machine. This Gramme machine formed a part of the exhibit of M. Breguet at the Centennial exhibition, and, for this and other reasons, is believed to be a good example of its class.

The apparatus employed by the sub-committee on electrical measurements, in their determinations, were kindly loaned, for the purpose, by the Committee on the Central High School of Philadelphia, and are from the large and valuable cabinet of philosophical apparatus of that institution.

The apparatus used to measure the power required to drive the electric machine, was a Brown Dynamometer, loaned by the Fales & Jenks Manufacturing Co., of Providence, R. I.

Mr. J. W. Sutton, of N. Y., also loaned us a spring dynamometer, which is a very compact instrument, and possesses peculiar advantages for use in many locations. The circumstances, however, under which our tests were made, rendered this less available, and it was, therefore, not used.

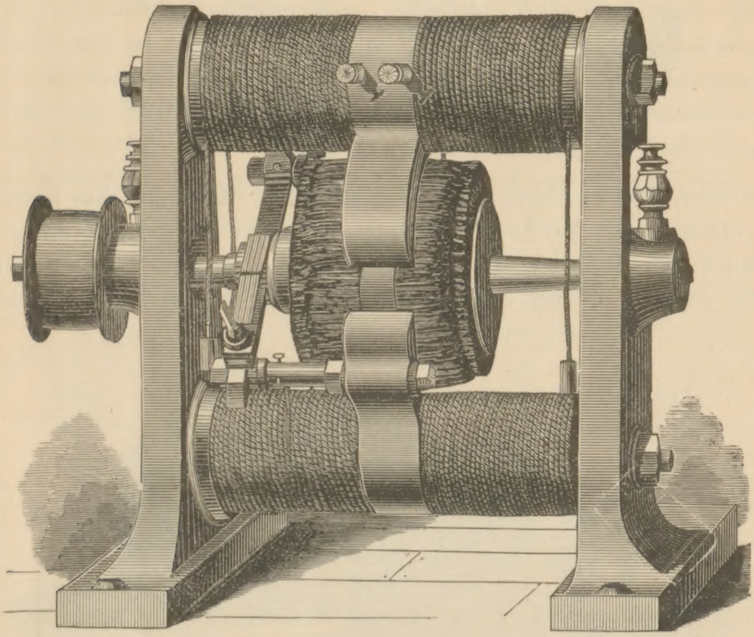
The source of power for the experiments was an upright steam-engine belonging to the Institute. It has 6″ bore of cylinder, and 8″ stroke, heavy fly-wheel 30″ diameter, and governor so adjusted as to give speeds from 100 to 250 revolutions per minute.

In measuring the power used, indicator diagrams were taken from the engine, as a check on the dynamometer readings, although the latter were relied upon in making our calculations, except in the case of the large Wallace machine. This machine requiring more power than could be supplied by the Institute's engine, or safely transmitted by the dynamometer, it was taken to the works of the I. P. Morris Co., and driven by an engine of 9″ bore and 18″ stroke, and the amount of "power consumed" determined from the indicator

diagrams. This determination was sufficient to demonstrate the fact that this machine possesses no economical advantages over the smaller one of the same make, but the "power consumed" is omitted from the table of results, as comparisons based on the different methods would be obviously unsatisfactory.

The following is a description of the machines submitted to examination. Their dimensions are given in Table I:

FIG. 1.



The Gramme machine, Fig. 1, consists of two cylindrical electro-magnets, with their combined poles extended by pieces of such shape as nearly to envelop the armature which rotates between them, Figs. 2 and 3. The armature is composed of a ring of soft iron, with insulated copper wire wound over its entire surface. This wire is divided into sixty coils connected successively at their ends, and the loops thus formed between each pair of coils are connected to the copper strips of the commutator. Fig. 2 represents the mode of winding this wire on the ring, only a few turns, however, being shown.

The commutator consists of copper strips equal in number to the armature coils, placed radially edgewise around the shaft of the

FIG. 2.

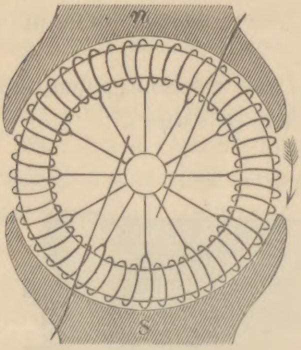
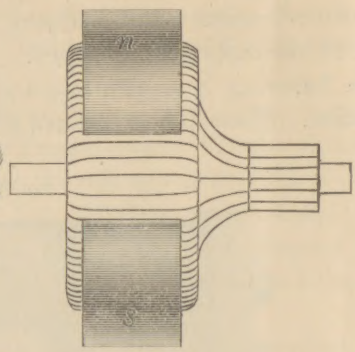
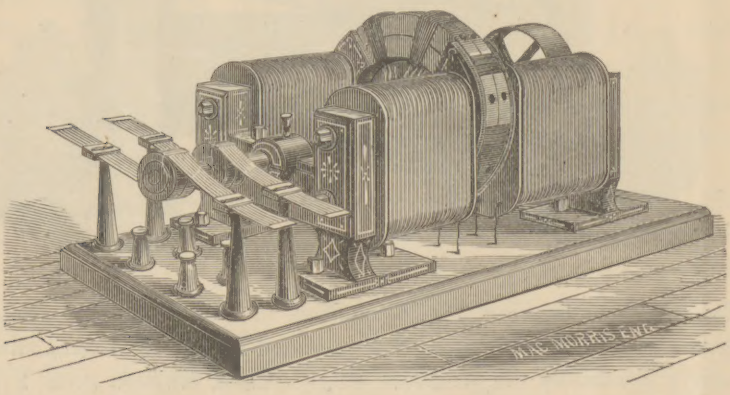


FIG. 3.



machine, and insulated from each other and the shaft, thus forming a cylinder, the surface of which is composed of alternate strips of copper and insulating material. Upon the surface of the commutator rest bundles of soft iron wire, by which the currents generated

FIG. 4.



in the armature coils are conducted to the external circuit. As the armature is rotated between the poles of the field magnets, currents of electricity are generated.

These machines are also constructed with two commutators, each connected respectively to alternate armature coils, in which case the

external circuit can be divided; but it is usual to pass both currents through the field coils, and then join them in the external circuit. This machine runs smoothly and very quietly, with few or no sparks at the commutator, and very little heating, the temperature of the armature being about 98° Fahr. after running nearly five hours.

The Brush machine, Fig. 4, has, for its magnetic field, two horseshoe electro-magnets, with their like poles facing each other, at a suitable distance apart, the circular armature rotating between them. In this machine the currents are generated in coils of copper wire, wound upon an iron ring, constituting the armature. This ring is not entirely covered by the coils, as in the Gramme armature, but the alternate uncovered spaces between the coils are almost completely filled by iron extensions from the ring, thus exposing large surfaces of the armature ring for the dissipation of heat, due to its constantly changing magnetism, as in the Pacinotti machine.

Fig. 5.

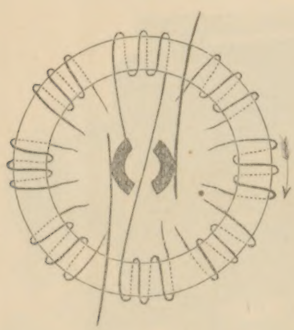
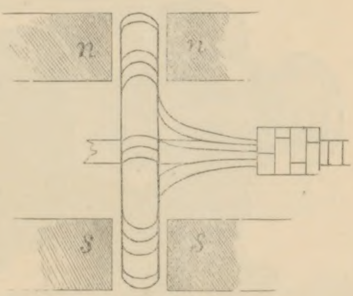


Fig. 6.



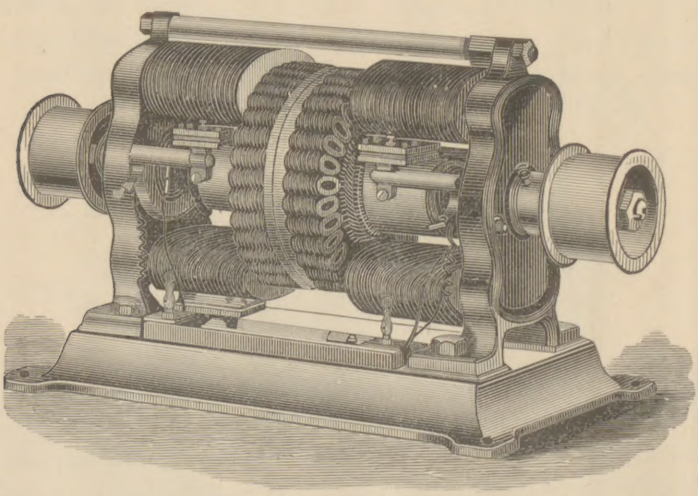
The ring revolves between the poles of two large field magnets, the two positive poles of which are at the same extremity of the diameter of the armature, and the two negative poles at the opposite extremity, each pair constituting practically extended poles of opposite character.

The coils on the armature ring are eight in number, opposite ones being connected end to end, and the terminals carried out to the commutator. Figs. 5 and 6 show this arrangement, only one pair of coils, however, being shown in Fig. 5 as connected. In order to place the commutator in a convenient position, the terminal wires are carried through the centre of the shaft, to a point outside the bearings.

The commutators are so arranged, that, at any instant, three pairs of coils are interposed in the circuit of the machine, working, as it were, in multiple arc, the remaining pair being cut out at the neutral point; while in the Gramme machine, the numerous armature coils being connected end to end throughout, and connections being made to the metal strips composing the commutator, two sets of coils in multiple arc are at one time interposed in the circuit, each set constituting one-half of the coils on the armature.

The commutator consists of segments of brass, secured to a ring of non-conducting material, carried on the shaft. These segments are divided into two thicknesses, the inner being permanently secured to the non-conducting material, and the outer ones, which take all the wear, are fastened to the inner in such a manner that they can be easily removed when required.

Fig. 7.



The commutator brushes, which are composed of strips of hard brass, joined together at their outer ends, are inexpensive and easily renewed. The high speed at which these machines are run, together with the form of the armature, cause the rotation of the latter to be considerably resisted by the air, and producing a humming sound, but otherwise they run smoothly; the heating of the armature being inconsiderable, not exceeding 120° Fahr. after four and three-quarter

hours' run. They are simple in construction, all the working parts being easily accessible, and the cost of maintenance low.

Fig. 4 represents the smaller Brush machine, which is identical in mechanical design with the larger, except that in the former there are two commutators, each of which is connected with alternate armature coils.

By this arrangement connections can be so made as to produce electric currents of high or low electromotive force (55 to 120 volts, as will hereafter be shown), or the conductor can be divided into two circuits, each of which can be utilized for producing its own light, or for performing other work.

In the Wallace-Farmer machine, Fig. 7, the magnetic field is also produced by two horseshoe electro-magnets, but with poles of opposite character facing each other. Between the arms of the magnets, and passing through the uprights supporting them, is the shaft, carrying at its centre the rotating armature.

Fig. 8.

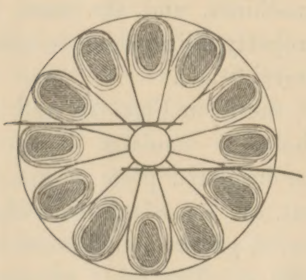
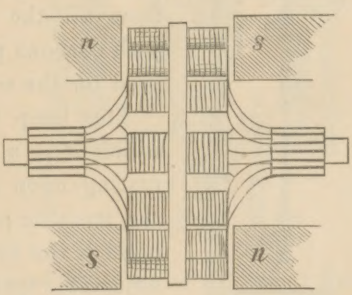


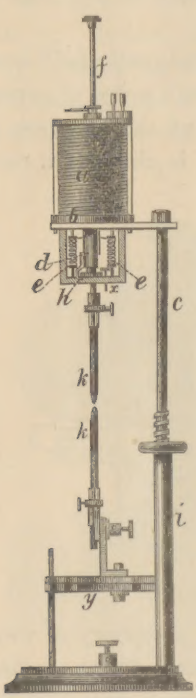
Fig. 9.



This consists of a disc of cast iron, near the periphery of which, and at right angles to either face, are iron cores, wound with insulated wire, thus constituting a double series of coils. These armature coils Figs. 8 and 9, being connected end to end, the loops so formed are connected in the same manner, and to a commutator of the same construction, as that of the Gramme. As the armature rotates, the cores pass between the opposed north and south poles of the field magnets, and the current generated depends on the change of polarity of the cores. It will be seen that this constitutes a double machine, each series of coils, with its commutator, being capable of use quite independently of the other; but in practice the electrical

connections are so made, that the currents generated in the two series of armature coils pass through the field-magnet coils, and are joined in one external circuit. This form of armature also presents considerable uncovered surface of iron to the cooling effect of the air, but its external form, in its fan-like action on the air, like that of the Brush, presents considerable resistance to rotation. In the Wallace-Farmer machine there was considerable heating of the armature, the temperature being sufficiently high to melt sealing-wax.

FIG. 10.



The Brush and Wallace-Farmer machines were accompanied by lamps, or carbon holders, which were thought by their makers to present advantages, if not for all machines, at least to be especially adapted to the requirements of their own; the usual "Serrin" lamp, which is made by M. Breguet for the Gramme machine, did not accompany the latter. The result of experiment, however, quickly established the suitability of the Brush lamp as the source of light from all the machines, and the same lamp, with carbons properly adjusted as to size, was used for the several trials.

This lamp is shown in Figs. 10 and 11, in which *a* is a helix of insulated copper wire, resting upon an insulated plate, *b*, upheld by the metallic post, *c*. Loosely fitted within the helix is the core, *d*, partially supported by the adjustable springs, *e*. The rod, *f*, passes freely through the centre of the core, *d*, and has at its lower end a clamp for holding the carbon pencil. A washer, *h*, of brass, surrounds the rod, *f*, just below the core, *d*, and has one edge resting on the lifting finger attached to the latter, while the other edge is overhung by the head of an adjustable screw stop, *x*.

The metal post, *c*, is supported and guided by a tubular post, *i*, secured to a suitable base plate. Attached to the lower end of the post, *c*, and passing out through a slot in *i*, is the arm, *y*, supporting an insulated holder for the lower carbon.

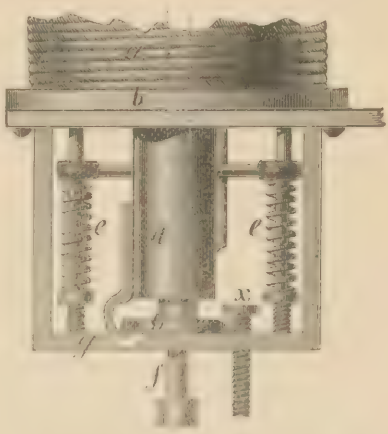
If now one conducting wire, from the machine, be connected to the base plate, and the other to the lower carbon holder, the current

of electricity will pass up through the posts, *i* and *c*, through the helix, *a*, rod, *f*, and the carbons, *k k*, thus completing the circuit.

The axial magnetism produced in the helix will draw up the core, *d*, and it, by means of the lifting finger, will raise one edge of the washer, *h*, which, by its angular impingement against the rod, *f*, clamps and lifts it to a distance controlled by the adjustable stop, *x*, but separating the carbon points far enough to produce the light.

As the carbons burn away, the increased length of the electric arc increases its resistance and weakens the magnetism of the helix, and, therefore, the coil, rod and carbon move downward by the force of gravity, until, by the shortening of the arc, the magnetism of the helix is strengthened and the downward movement arrested. When, however, the downward movement is sufficient to bring the clutch-washer, *h*, to the support, *l*, it will be released from the clamping effect of the lifting finger, and the rod, *f*, will slip through until arrested by the upward movement of the core, due to the increased magnetism of the helix.

Fig. 11.

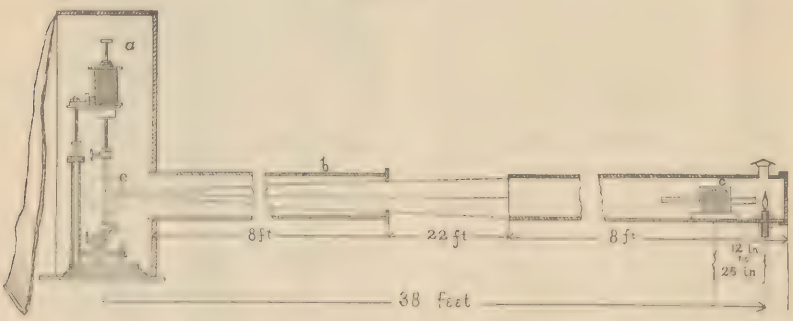


The normal position of the clamp-washer is with the edge under the adjustable stop, just touching the support, *l*, the office of the core being to regulate the slipping of the rod through it. If, however, the rod, from any cause, falls too far, it will instantly and automatically be raised again, as at first, and the carbon points thus continued at the proper distance from each other.

In the lamp used in these experiments, the helix was composed of two separate insulated wires wound together, so that, by means of suitable pin contacts, shown at the top of Fig. 10, they could be connected either in couples or end to end, thus varying the intensity of the magnetism of the helix. This, in connection with varying the weight to be lifted by the magnetism of the helix, either by loading the core or increasing the upward thrust of the springs, enabled us to adjust the lamp to suit the varying qualities of the currents dealt with.

In order to make the measurements as accurate as possible, it was found necessary so to arrange the apparatus that no reflected or diffused light should fall on the photometer, and thus introduce an element of error. The arrangement of the apparatus to accomplish this is shown in Fig. 12. The electric lamp was enclosed in a box, open at the back for convenience of access, but closed with a non-reflecting and opaque screen during the experiments. Projecting from a hole in the front of the box was a wooden tube, *b*, 6″ square inside and 8′ long, with its inner surface blackened to prevent reflection, thus allowing only a small beam of direct light to leave the box. This beam of light passed into a similar wooden tube, *c*, placed at a proper distance from the first, and holding in its farther end the standard candle, *d*.

FIG. 12.



This tube also held the dark box of a Bunsen photometer, mounted on a slide, so as to be easily adjusted at the proper distance between the two sources of light. A slit in the side of the tube enabled the observer to see the diaphragm. The outer end of the second tube was also covered with a non-reflecting hood, and the room was, of course, darkened when photometric measurements were taken. The rigid exclusion of all reflected or diffused light is believed to be the only trustworthy method of obtaining true results, and will, no doubt, account in a large measure for the lower candle-power obtained by these experiments than that obtained by many previous experimenters.

The difficulties encountered in the measurement of the light arising from the difference in color, were at first thought to be considerable, but further practice and experience enabled the observer to overcome them to such an extent that the error arising from this cause is inconsiderable, being greatly less than that due to the fluctuations of the electric arc.

The advantage to be derived from using a larger source of light than the standard candle, in measuring the electric light, was considered. A gas-flame, giving 20 candles' light, and the oxy-hydrogen light, so adjusted as to give 70 to 136 candles, were carefully measured and used as a comparison. Both of these were found unsatisfactory, and the measurements relied on for our calculations were made entirely with a standard candle, carefully corrected for any variation of consumption from 120 grains per hour.

Were much higher intensities of light to be measured, it would be well to use, as a means of comparison, a large gas-burner or a multiple-wick lamp, such as are employed in lighthouse service, its power being constantly checked by measurements with the standard candle and separate photometer; but, with the volume of light dealt with in these experiments, the candle was sufficiently large, and its direct use greatly reduced the chance of error.

In the earlier experiments, measurements of light, current and power were made simultaneously, thus establishing standard references by which after-experiments upon the different points were connected.

In determining the amount of light produced by each machine, it was run continuously for from four to five hours, and observations made at intervals, care being taken to maintain the speed and other conditions normal. One of the most important conditions necessary to insure correct results, was the relative position of the carbon points. Great care was taken that the axes of the two sticks or pencils of carbon were in the same line, so that the light produced should be projected equally in all directions. Were the axes of the carbon pencils not in the same line, a much greater quantity of light would be projected in one direction, and the result of calculation of the light produced, based on the inverse square of the distance from the photometer, would be too great or too small, accordingly as this adjustment was in the one on the other direction.

To facilitate observations during the experiments, there was attached, at *e*, to the side of the box *a* holding the electric lamp, a focussing lens, with its axis at right angles to the beam of light, to the photometer, and an image projected upon a screen enabling the observer to see the condition and position of the carbon points without fatiguing the eye. Photographs were also taken, from time to time, at the moment of making the photometric observations—thus securing a permanent record of the condition of the carbon points.

Another difficulty in determining the exact photometric value of the electric light, is the fluctuation, or rather the moving from side to side, of the electric arc, and great care was taken so to adjust the

Fig. 13.

Fig. 14.

From Large Brush Machine.

Fig. 15.

Fig. 16.

From Small Brush Machine.

conditions, that the arc or flame should be steady, and equally distributed about the ends of the carbon pencils.

Fig. 17.[1]

Fig. 18.

From Gramme Machine.

Fig. 19.

Fig. 20.

From Small Wallace Machine.

Figs. 13 to 20 are full size, exact reproductions of the photographs taken, and fairly represent the average condition of the carbon when observations were made.

[1] The voltaic arc should have been shown in Fig. 17, as in Fig. 19. All the carbons used were coated with copper.

It was found that although there was a slow consumption of the negative carbon, there was, at the same time, a constant "stalagmitic" growth of particles carried from the positive carbon by the action of the electric current. These stalagmites assumed different forms, as shown in the cuts, but no particular form seemed to be produced by the current from the different machines, except that the deposits on the negative carbon would become greater with increased current. These deposits would build up gradually until they had assumed the forms shown in Figs. 18 and 20; then growing narrower near the base, until, by a weakening of the current by this and the consumption of the upper carbon, the lamp would readjust itself, and the piece would drop off. The effect of these growths on the intensity of the light was scarcely appreciable, except for a few seconds before and after the readjustment of the lamp.

Fig. 21.

Experiments were also made to determine what effect on the amount of light produced by so adjusting the carbons, that the front edge of the upper one was in line with the centre of the lower one. Fig. 21 shows such an adjustment, and is from a photograph taken while measuring the light produced from the small Brush machine, running at 1250 revolutions per minute, and resulting as follows:

Front, ...	2218 candles.
Side, ...	578 "
"	578 "
Back, ...	111 "
	3485 ÷ 4 = 871.

The light produced by the same machine, under the same conditions, except the carbons being adjusted in one vertical line, was 525 candles. This would seem to indicate that nearly 66 per cent. more light was produced by this adjustment of the carbons; but a close study of the conditions satisfies us that such is not the case, and that there is no advantage to be derived from such adjustment, except when the light is intended to be used in one direction only.

TABLE I.

SHOWING WEIGHT, POWER ABSORBED, LIGHT PRODUCED, ETC., BY DYNAMO-ELECTRIC MACHINES TESTED BY A COMMITTEE OF THE FRANKLIN INSTITUTE, 1877–8.

NAME OF MACHINE.	Weight in pounds.	COPPER WIRE IN				Revolutions of Armature per minute	Foot-pounds of power consumed.	Horse-power.	LIGHT PRODUCED IN STANDARD CANDLES.		Foot-pounds of power consumed per candle light.	Size of carbons.	LENGTH OF CARBON CONSUMED PER HOUR.	
		ARMATURE		FIELD MAGNETS.										
		Size.	Weight.	Size.	Weight.				Total.	Per h.-p.			+	—
Large Brush, .	475	·081 in.	32 lbs.	·134 in.	100 lbs.	1340	107·606	3·26	1230	377	87·4	$\frac{3}{8} \times \frac{3}{8}$	1·78	·34
Small Brush, .	390	·063 in.	24 lbs.	·096 in.	80 lbs.	1400	124·248	3·76	900	239	137·	$\frac{3}{8} \times \frac{3}{8}$	1·91	·58
Large Wallace,	600	·042 in.	50 lbs.	·114 in.	125 lbs.	800			823					
Small Wallace,	350	·043 in.	18¾ lbs	·098 in.	41 lbs.	1000	128·544	3·89	440	113	292·	$\frac{1}{4} \times \frac{1}{4}$	2·45	·073
Gramme, . .	366	·059 in.	~~104~~ lbs.	·108 in.	~~104~~ lbs.	800	60·992	1·84	705	383	85·	$\frac{1}{4} \times \frac{1}{4}$	3·15	·55

We would here call the attention of those who may compare our results with those obtained at the recent experiments at South Foreland, England, to the following statement upon this point, in the report of Mr. Jas. N. Douglas, Engineer to the Trinity House, page 16 of the official report:

"I have found this arrangement of the carbons (the axis of the bottom carbon nearly in the same vertical plane as the front of the top carbon), and assuming the intensity of the light with the carbons having their axis in the same vertical line to be represented by 100, the intensity of the light in four directions in azimuth, say E., W., N. and S., will be nearly as follows:

East or front intensity, . .	287 to 100
North or side " . .	116 to 100
South or " " . .	116 to 100
West or back " . .	38 to 100
	557 ÷ 4 = 139 to 100."

* * * * * * * * *

'In measuring the candle-power of the light produced by each machine, I have given the mean intensity obtained in the direction of the photometer, the carbons in lamp working with the Holmes & Alliance machines being always arranged with the axes in the same vertical line, and the carbons in the lamp working the Gramme and Siemens machine being always arranged with the front edge of the top carbon nearly on the centre of the bottom carbon."

It is, therefore, evident that the results given by Mr. Douglas must be divided by 2·87 in making a comparison with those obtained by us.

Thus, in the table on page 31, official report, in the column headed Light produced by H. P. in standard candles, he gives for the Gramme machine condensed beam 1257, but if this be divided by 2·87 we have 438 candles, which is, no doubt, still too high, our result of 383 candles per H. P. for the Gramme, being obtained under the careful and rigid conditions before named.

REPORT OF THE INVESTIGATIONS OF THE SUB-COMMITTEE ON ELECTRICAL MEASUREMENTS.

By Profs. EDWIN J. HOUSTON and ELIHU THOMSON.

Now that the conversion of motive power into electricity, and the use of the latter for lighting, the deposition of metals, etc., are rapidly gaining in importance, it has become desirable that reliable data be obtained as to the efficiency of the various types of machines designed for producing electrical current from motive power.

In entering this comparatively new field of research, we have been met by peculiar difficulties, owing to conditions, that do not exist in the various forms of batteries used as sources of electrical power.

In many battery circuits a high external resistance may be employed, and the electromotive force remain comparatively constant, while in dynamo-electric machines, in which the reaction principle is employed, the introduction of a very high external resistance into the circuit must be necessarily attended by decided variations in the electromotive force, due to changes in the intensity of the magnetic field in which the currents have their origin. Moreover, a considerable difficulty is experienced in the great variations in the behavior of these machines when the resistance of the arc, or that of the external work, is changed. Changes, due to loss of conductivity by heating, also take place in the machine itself.

The variations above mentioned are also attended by changes in the power required to drive the machine, and in the speed of running, which again react on the current generated.

There are certain normal conditions in the running of dynamo-electric machines designed for light, under which all measurements must be made, viz.:

1. The circuit must be closed, since, on opening, all electrical manifestations cease.

2. The circuit must be closed through an external resistance equal to that of the arc of the machine.

3. The arc taken as the standard must be the normal arc of the machine. This condition can only be fulfilled by noticing the be-

havior of the machine while running, as to the absence of sparks at the commutator, the heating of the machine, the regularity of action in the consumption of carbons in the lamp, etc.

4. The speed of the machine must be, as nearly as possible, constant.

5. The power required to maintain a given rate of speed must be, as nearly as possible, constant.

The machines submitted to us for determinations, were as follows, viz.:

1. Two machines of different size, and of somewhat different detailed construction, built according to the invention of Mr. C. F. Brush, and styled respectively in our report as A^1, the larger of the two machines, and A^2 the smaller.

2. Two machines known as the Wallace-Farmer machines, differing in size, and in minor details of construction, and designated respectively as B^1, the larger of the two, and B^2, the smaller. In the case of the machine B^1, the experiments were discontinued after the measurement of the resistances were made, insufficient power being at our disposal to maintain the machine at its proper rate of speed.

3. A Gramme machine of the ordinary construction.

All the above machines are constructed so that the whole current traverses the coils of the field magnets, being single current machines, in which the reaction principle is employed. In the case of the machine designated A^2, the commutators are so arranged as to permit the use of two separate circuits when desired.

For the purpose of preserving a ready measure of the current produced by each machine, under normal conditions, a shunt was constructed by which an inconsiderable but definite proportion of the current was caused to traverse the coils of a galvanometer, thus giving with each machine, a convenient deflection which could at any time be reproduced. As the interposition of this shunt in the circuit did not appreciably increase its resistance, the normal conditions of running were preserved.

As indicating the preservation of normal conditions in any case, the speed of running and the resistances being the same as in any previous run, it was found that when there was an equal expenditure of power, as indicated by the dynamometer, the current produced, as indicated by the galvanometer, was in each case the same.

Certain of the machines experimented with heated considerably on a prolonged run; most of the tests, therefore, were made when the machines were as nearly as possible at about the temperature of the surrounding air. It is evident that no other standard could be well adopted, as under a prolonged run the temperature of the different parts of the machine would increase very unequally; and, moreover, it would be impossible to make any reliable measurements of the temperatures of many such parts.

In measuring the resistance of the machines, a Wheatstone's bridge, with a sliding contact, was used in connection with a delicate galvanometer and a suitable voltaic battery. In taking the resistances of the machines, several measurements were made with the armatures in different positions, and the mean of these measurements taken as the true resistance.

It was, of course, a matter of the greatest importance to obtain a value for the resistance of the arc in any case, since upon the relative values of this resistance, and that of the machine, the efficiency would in any given case, to a great extent, depend. In each case, the arc of which the resistance was to be taken, was that which was obtained when each machine was giving its average results as to steadiness of light and constancy of the galvanometer deflection.

The method adopted for the measurement of the arc was that of substitution, in which a resistance of German silver wire immersed in water, was substituted for the arc, without altering any of the conditions of running. This substituted resistance was afterwards measured in the usual way, and gave, of course, the resistance of the arc. It could, therefore, when so desired, serve as a substitute for the arc. No other method of obtaining the arc resistance appeared applicable, since the constancy of the resistance of the arc required the passage of the entire current through the carbons.

It may be mentioned, as an interesting fact in this connection, that when the current flowing was great, the arc corresponding thereto had a much lower resistance than when the current was small. This fact is, of course, due to increased vaporization, consequent on increased temperature in the arc.

In determining the true arc resistance, the resistance of the electric lamp controlling the arc was measured separately, and deducted from the result obtained with the German silver wire substitute.

For ease of obtaining a resistance of German silver wire equal in any case to that of the arc, a simple rheostat was constructed, by winding, upon an open frame, such a length of wire as was judged to be in excess of the resistances of any of the arcs to be measured. By means of a sliding contact, successive lengths of the wire were added until the conditions as above stated were reproduced. The figure shows the arrangement of the rheostat. With this arrangement, no difficulty was experienced in reproducing the same conditions of normal running, as when the arc was used. The same conducting wires were used throughout these experiments. Being of heavy copper, their resistance was low, viz.: about ·016 ohm.

Having thus obtained the circuit resistances, we proceeded to determine the value of the current. Here the choice of a number of methods presented itself. We selected two methods, one based on the production of heat in a circuit of known resistance, and the other upon the comparison of a definite proportion of the current with that of a Daniell's battery.

In the application of the first method, eight litres of water, at a known temperature, were taken, and placed in a suitable non-conducting vessel. In this was immersed the German silver wire before mentioned, and the sliding contact so adjusted as to afford a resistance equal to that of the normal arc of the machine under consideration. This was now introduced into the circuit of the machine. All these arrangements having been made, the temperature of the water was accurately obtained, by a delicate thermometer, reading readily to quarter degrees Fahrenheit. The current from the machine running under normal conditions was allowed to pass, for a definite time, through the calorimeter so provided. From the data thus obtained, after making the necessary corrections as to the weight of the water employed, the total heating effect in the arc and lamp, as given in Table II, was deduced.

Since the heat in various portions of an electrical circuit is directly proportional to the resistance of those portions, the total heat of the circuit was easily calculated, and is given in Table III, in English heat units. For ease of reference, the constant has been given for

conversion of these units into the now commonly accepted units of heat.

Having thus obtained the heating effect, the electrical current is readily determined by the well known formula,

$$C = \sqrt{\frac{W\,h \times 772}{R\,t\,c}},$$

where $C =$ the veber current per ohm, W the weight of water in pounds, h the increase of temperature in degrees Fahr., 772 Joule's constant, R the resistance in ohms, t the time in seconds, and c the constant, ·737335, the equivalent in foot-pounds of one veber per per ohm per second. The currents so deduced for the different machines are given in Table IV.

The other method employed for obtaining the current, viz., the comparison of a definite portion thereof, with the current from a Daniell's battery, was as follows: a shunt was constructed, of which one division of the circuit was ·12 ohm, and the other 3000 ohms. In this latter division of the circuit was placed a low-resistance galvanometer, on which convenient deflections were obtained. This shunt being placed in the circuit of the machine, the galvanometer deflections were carefully noted. To the resistance afforded by the shunt, such additional resistance was added, as to make the whole equal to that of the normal arc of the machine. These substituted resistances were immersed in water, in order to maintain an equable temperature.

Three Daniell's cells were carefully set up and put in circuit with the same galvanometer used above, and with a set of standard resistance coils. Resistances were unplugged sufficient to produce the same deflections as those noted with the shunt above mentioned. The shunt ratio, as nearly as could conveniently be obtained, was $\frac{1}{25000}$. Then the formula,

$$C = \frac{s\,n \times 1{\cdot}079}{R},$$

where C equals the veber current, s the reciprocal of the shunt ratio, n the number of cells employed, 1·079 the assumed normal value of the electromotive force of a Daniell's cell, and R the resistances in the circuit with the battery, gives at once the current. In comparison

with the total resistances of the circuit, the internal resistance of the battery was so small as to be neglected.

The results obtained were as follows:

Name of Machine.	Shunt ratio.	Number of Daniell's cells.	Resistances unplugged.	Speed of Machine.
Large Brush, . .	$\frac{1}{25000}$	3	2710 ohms.	1340 rev.
Small Brush, . .	"	"	3700 "	1400 "
Wallace-Farmer, { .	"	"	8320 "	844 "
Wallace-Farmer, { .	"	"	6980 "	1040 "
Gramme, ...	"	"	4800 "	800 "

The veber currents, as calculated from the above data, are given in Table IV.

From the results thus derived, the electromotive force was deduced by the general formula,

$$E = C \times R.$$

The electromotive force thus calculated will be found in Table IV.

Statements are frequently made, when speaking of certain dynamo-electric machines, that they are equal to a given number of Daniell's, or other well-known, battery cells. It is evident, however, that no such comparison can properly be made, since the electromotive force of a dynamo-electric machine, in which the reaction principle is employed, changes considerably with any change in the relative resistances of the circuit of which it forms a part, while that of any good form of battery, disregarding polarization, remains approximately constant. The internal resistance of dynamo-electric machines is, as a rule, very much lower than that of any ordinary series of battery cells, as generally constructed, and, therefore, to obtain with a battery, conditions equivalent to those in a dynamo-electric machine, a sufficient number of cells in series, would have to be employed to give the same electromotive force; while, at the same time, the size of the cells, or their number in multiple arc, would require to be such that the internal resistance should equal that of the machine.

Suppose, for example, that it be desired to replace the large Brush machine by a battery whose electromotive force and internal and external resistances are all equal to that of the machine, and that we adopt as a standard a Daniell's cell, of an internal resistance of, say, one ohm. Referring to Table IV, the electromotive force of

this machine is about 39 volts, to produce which about 37 cells, in series, would be required; but, by Table II, the internal resistance of this machine is about ·49 ohm. To reduce the resistance of our standard cell to this figure, when 37 cells are employed in series, 76 cells, in multiple arc, would be required. Therefore, the total number of cells necessary to replace this machine would equal 37 × 76, or 2812 cells, working over the same external resistance. It must be borne in mind, however, that although the machine above-mentioned is equal to 2812 of the cells taken, that no other arrangement of these cells than that mentioned, viz., 76 in multiple arc, and 37 in series, could reproduce the same conditions, and, moreover, the external resistances must be the same. The same principles, applied to the other machines, would, when the internal resistance was great, require a large number of cells, but arranged in such a way as to be extremely wasteful, from by far the greater portion of the work being done in overcoming the resistance of the battery itself.

The true comparative measure of the efficiency of dynamo-electric machines as means for converting motive power into work derived from electrical currents, whether as light, heat, or chemical decomposition, is found by comparing the units of work consumed with the equivalent units of work appearing in the circuit external to the machine. In Table V, the comparative data are given. In the first column the dynamometer reading gives the total power consumed; from which are to be deducted the figures given in the second column, being the work expended in friction, and in overcoming the resistance of the air; although, of course, it must be borne in mind, that, that machine is the most economical in which, other things being equal, the resistance of the air and the friction, are the least. The third column gives the total power expended in producing electrical effects, a portion only of which, however, appears in the effective circuit, the remainder being variously consumed in the production of local circuits in the different masses of metal composing the machines. This work eventually appears as heat, in the machine. Columns four, five and six give respectively the relative amounts of power variously appearing as heat in the arc, in the entire circuit, and as heat due to local circuits in the conducting masses of metal in the machine, irrespective of the wire. This latter consumption of force may be conveniently described as due to the *local action* of the machine, and is manifestly comparable to the well known local action of the

voltaic battery, since in each case it not only acts to diminish the effective current produced, but also adds to the cost.

We desire to call attention to the fact, that in all the determinations conducted by us, we have been particularly careful to ensure a definite relation between the external and internal resistances in each case, a condition of paramount importance in the effective working of these machines. It is evident indeed, that no determinations made with an unknown or abnormal external resistance can be of any value, since the proportion of work done, in the several portions of an electrical circuit, depends upon, and varies with, the resistances they offer to its passage. If, therefore, in separate determinations with any particular machine, the resistance of that part of a circuit of which the work is measured be, in one instance large, in proportion to that of the remainder of the circuit, and in another small, the two measurements thus made would give widely different results, since in the case where a large resistance was interposed in this part of the circuit, the percentage of the total work appearing there would be greater than if the small resistance had been used.

When an attempt has been made to determine the efficiency of a single machine, or of the relative efficiency of a number of machines, by noting the quantity of gas evolved in a voltameter, or by the electrolysis of copper sulphate in a decomposing cell, when the resistance of the voltameter or decomposing cell did not represent the normal working resistance, it is manifest that the results cannot properly be taken as a measure of the actual efficiency.

In Table II it will be found, that in general, where the machine used had a high internal resistance, the arc resistance normal to it was also high, but they are not necessarily dependent upon each other. The arc resistance depends on the intensity of the current, the nature of the carbons, and on their distance apart. Other conditions being the same, the resistance of the arc is less when the current is great.

Since all the machines examined were built for lighting, it will readily be seen that, other things being equal, that machine is the most economical in which the work done in the arc bears a considerable proportion to that done in the whole circuit, and since, with any given current, the work is proportional to the resistance, we have in Table II the data for comparison in this regard. For example, in the second determination of A^1, the large Brush machine, the resistance of the arc constitutes considerably more than one-half the

TABLE II.—Resistances of Dynamo-Electric Machines.

From Determinations by Edwin J. Houston and Elihu Thomson.

NAME OF MACHINE.	Temperature in degrees F.	Resistances		Resistance of conducting Wire.	Resistance of Lamp, exclusive of Arc.	Corrected Resistances		Total resistance of the Circuit, Ohms.	REMARKS.
		Of Machine +conductor.	Of Arc —Lamp.			Of Machine —conductor.	Of Arc —Lamp.		
A^1, Large Brush, .	73½	·485	·57	·016	·032	·483	·54	1·055	At beginning of run.
A^1, " " .	88	·495	·82	·016	·032	·493	·79	1·315	After running 25 min.
A^2, Small Brush, .	74	1·255	1·70	·016	·032.	1·239	1·67	2·955	Arranged for low resist.
A^2, " " .	74	5·06		·016		5·044			" " high "
B^1, Large Wallace,	74	4·60	1·98	·016	·032	4·584	1·95	6·58	Machine cold.
B^1, " "	118	5·13							After 40 min. run.
B^2, Small Wallace,	74	4·96	2·87	·016	·1025	4·944	2·77	7·83	At 844 rev.
B^2, " "	74	4·96	3·24	·016	·1025	4·944	3·18	8·24	" 1000 rev.
Gramme, ...	68	1·685	1·35	·016	·1025	1·669	1·25	3·04	Arc not normal.
"	68	1·685	1·97	·016	·1025	1·669	1·87	3·66	Arc normal.

total resistance of the entire circuit, while in B^2, the small Wallace-Farmer machine, it constitutes somewhat more than one-third the total resistance. These relative resistances give, of course, only the proportion of the current generated, which is utilized in the arc as light and heat, the conditions of power consumed to produce the current not being there expressed.

During any continued run, the heating of the wire of the machine, either directly by the current, or indirectly from conduction from those parts of the machine heated by local action, as explained in a former part of this report, produces an increased resistance, and a consequent falling off in the effective current. Thus, in Table II, at the temperature of 73·5° Fahr., A^1, the large Brush machine, had a resistance of ·485 ohm, while at 88° Fahr., at the armature coils, it was ·495 ohm. These differences were still more marked in the case of B^1.

In A^2, the small Brush machine, it will be noticed that two separate values are given for the resistance of the machine. These correspond to different connections, viz., the resistance, 1·239 ohms, being the connection at the commutator for low resistance, the double conducting wires being coupled in multiple arc, while 5·044 ohms represent the resistance when the sections of the double conductor are coupled at the commutator in series.

Referring to Table III, the numbers given in the column headed "Heat in Arc and Lamp," are the measure of the total heating power in that portion of the circuit external to the machine. They do not, however, in the case of any machine, represent the energy which is available for the production of light, which depends also on the nature and the amount of the resistance over which it is expended. For example, the heat in arc and lamp are practically the same in each of the Brush machines, if the measurement of the smaller of these machines be taken at the higher speed. The amount of light produced, however, is not the same in these two instances, being considerably greater in the case of the larger machine. The explanation of this apparent anomaly is undoubtedly to be found in the different resistances of the arcs in the two cases. In the large Brush machine the carbons are nearer together than when the small machine is used. This suggests the very plausible explanation, that the cause of the difference is to be attributed to the fact, that, although the total heating effect is equal in each case, when the large machine

TABLE III.—Thermic Effects of Dynamo-Electric Machines.

From Determinations by Edwin J. Houston and Elihu Thomson.

Name of Machine.	Galvanometer deflection with shunt.	Heating Effect in Arc and Lamp.			Resistance of Calorimeter equal to arc.	Heat in arc and lamp, in pounds H_2O, 1° F.	Total heat of the circuit, in lbs. H_2O, 1° F.	Heat per ohm, per second.	Speed of machine rev. per min.	Dynamometer reading, including friction.
		Lbs. H_2O.	Increase degrees Fahr.	Duration of run.						
A^1, Large Brush, . .	$51\frac{1}{2}$°	18·64	23·25	10	·82	43·338	69·49	·881	1340	107606
A^2, Small Brush, . .	34	18·63	9·09	5	1·70	33·87	58·87	·332	1200	117700
A^2, " " . .	37	18·63	18·66	8	1·70	43·45	75·57	·426	1400	124248
B^2, Small Wallace, . .	$25\frac{1}{2}$	18·63	11·50	12	2·87	17·85	48·70	·104	844	97068
B^2, " " . .	$25\frac{1}{2}$	18·63	4·92	6	2·87	15·28	41·69	·089	844	97068
B^2, " " . .	$24\frac{1}{2}$	18·64	10·75	10	3·28	20·04	50·34	·102	1040	128544
Gramme, ...	38	18·64	16·25	10	1·97	30·29	56·28	·256	800	60992

For conversion to new heat units — 1 lb. water, 1° F., = 259·185 grammes of water, 1° C.

is used, the heat produced is evolved in a smaller space, and its temperature, and consequent light-giving power, thereby largely increased.

It would seem, indeed, that any future improvements made in the direction of obtaining an increased intensity of light from a given current, will be by concentrating the resistance normal to the arc in the most limited space practicable, thereby increasing the intensity of the heat, and, consequently, its attendant light.

It may be noted, in this connection, that in all the cases in which the resistance of the arc was low, the photometric intensity was high. This, indeed, might naturally be expected, since a great intensity of heat would, under existing conditions of the use of the arc, admit of increased vaporization, and consequent lowering of the resistance.

In the column headed "Total Heat of Circuit," are given the quantities of heat developed in the whole circuit, which numbers, compared with those in the preceding column, furnish us with the relative proportions of the work of the circuit, which appear in the arc and lamp.

The column headed "Heat per ohm per second," gives the relative work per ohm of resistance in each case, and these numbers, multiplied by the total resistance, give the total energy of the current expressed in heat units per second.

In Table IV are given the results of calculation and measurement, as to the electrical work of each machine. It is evident, to those acquainted with the principles of electrical science, that in the veber current and the electromotive force, we have the data for comparing the work of these machines with that of any other machine or battery, whether used for light, heat, electrolysis, or any other form of electrical work.

As might be supposed, the values given in Table IV, of the veber current, approximate relatively to the photometric values, as will be seen from an examination of that part of the general report of the Committee relating to photometric measurements.

The values of the veber current, as deduced from the heat developed, and from the comparison with a Daniell's cell, do not exactly agree; nor could this have been expected, when the difficulty of minutely reproducing the conditions as to speed, resistance, etc., is considered.

TABLE IV.—Current and Electromotive Force of Dynamo-Electric Machines.

From Determinations by Edwin J. Houston and Elihu Thomson.

Name of Machine.	Veber Current per ohm per sec.		Electromotive Force in Volts.		Per cent. of the work of current appearing in the arc.	Corresponding Dynamometric Values.	Remarks.
	From heat developed.	By comparison with Daniell's batt.	Calc. from heat and resistance.	By comparison with Daniell's batt.			
A^1, Large Brush, . .	30·37	29·87	39·94	39·28	60·08	107606	Speed 1340 rev.
A^2, Small Brush, . .	18·63		55·05			117700	" 1200 "
A^2, " " . .	21·12	21·87	62·41	64·63	56·51	124248	" 1400 "
B^2, Small Wallace, .	10·42	9·73	81·59	76·19	35·38	97068	" 844 "
B^2, " " .	9·64		75·48				" 844 "
B^2, " " .	10·33	11·16	85·12	91·96	38·59	128544	" 1040 "
Gramme, ...	16·38	16·86	59·95	61·71	51·09	60992	" 800 "

By comparison of the electromotive force of the different machines, it appears that no definite unit seems to have been aimed at by all the makers as that best adapted to the production of light.

Table V is designed especially to permit a legitimate comparison of the relative efficiency of the machines, as well as their actual efficiency in converting motive power into current. The actual dynamometer reading, for which we are indebted to the sub-committee on the measurement of power, is given in the first column. On account of differences of construction, and differences in speed of running, the friction and resistance of the air vary greatly, being least with the Gramme, as might be expected, since the form of the revolving armature, and the speed of the machine, conduce to this result. This is, of course, a point greatly in favor of the Gramme machine.

That portion of the power expended available for producing current is given in the third column, being the remainder, after deducting the friction, as above mentioned; but this power is not in any case fully utilized in the normal circuit. This is found to be the case by comparing calculations of the total work of the circuit in foot-pounds, as given in the appropriate column, with the amount expended in producing such current.

For instance, in the case of A^1, the large Brush machine, the available force for producing current is 89656 F. P. per minute, of which only 53646 reappear as heat in the circuit. The balance is most probably expended in what we have termed *local action*, that is, the production of local currents in the various conducting masses of metal composing the machine. The amount thus expended in local action is given in the column designated "F. P. unaccounted for in the Circuit." A comparison of the figures in this column is decidedly in favor of the Gramme machine, it requiring the smallest proportion of power expended, to be lost in local action. When, however, we consider that the current produced by the large Brush machine is nearly double that produced by the Gramme, the disproportion in the local action is not so great. The columns containing the percentages of "Power utilized in the Arc," and "Useful Effect after deducting Friction," need no special comment.

The determinations which we have made, as described in the foregoing part of this report, have enabled us to form the following

TABLE V.—Effects of Dynamo-Electric Machines in Foot-Pounds per Minute.

From Determinations by Edwin J. Houston and Elihu Thomson.

Name of Machine.	Dynamometer reading. F. P. consumed.	Friction and resistance of air.	F. P. consumed, after deducting friction.	F. P. appearing in arc as heat.	F. P. appearing in whole circuit.	F. P. unaccounted for in the circuit.	Per cent. of power utilized in arc.	Per cent. of effect after deduct. friction.
A^1, Large Brush, .	107606	17950	89656	33457	53646	36010	31	37½
A^2, Small Brush, .	117700	12328	105372	26148	45448	59924	22	25
A^2, " " . .	124248	14976	109272	33543	58340	50932	27	31
B^2, Small Wallace, .	97068	7800	89268	13780	37596	51672	14	15½
B^2, " " .	128544	11072	117472	15469	38862	78610	12	13
Gramme, . .	60992	4512	56480	23384	43448	13032	38	41

For conversion into Gramme-metres — 1 foot-pound = 138 Gramme-metres, nearly.

opinions as to the comparative merits of the machines submitted to us for examination.

1. The Gramme machine is the most economical, considered as a means for converting motive power into electrical current, giving in the arc a useful result equal to 38 per cent., or to 41 per cent. after deducting friction and the resistance of the air. In this machine the loss of power in friction and local action is the least, the speed being comparatively low. If the resistance of the arc is kept normal, very little heating of the machine results, and there is an almost entire absence of sparks at the commutator.

2. The large Brush machine comes next in order of efficiency, giving in the arc a useful effect equal to 31 per cent. of the total power used, or 37½ per cent. after deducting friction. This machine is, indeed, but little inferior in this respect to the Gramme, having, however, the disadvantages of high speed, and a greater proportionate loss of power in friction, etc. This loss is nearly compensated by the advantage this machine possesses over the others of working with a high external compared with the internal, resistance, this also ensuring comparative absence of heating in the machine. This machine gave the most powerful current, and consequently the greatest light.

3. The small Brush machine stands third in efficiency, giving in the arc a useful result equal to 27 per cent., or 31 per cent. after deducting friction. Although somewhat inferior to the Gramme, it is, nevertheless, a machine admirably adapted to the production of intense currents, and has the advantage of being made to furnish currents of widely varying electromotive force. By suitably connecting the machine, as before described, the electromotive force may be increased to over 120 volts. It possesses, moreover, the advantage of division of the conductor into two circuits, a feature which, however, is also possessed by some forms of other machines. The simplicity and ease of repair of the commutator are also advantages. Again, this machine does not heat greatly.

4. The Wallace-Farmer machine does not return to the effective circuit as large a proportion of power as the other machines, although it uses, in electrical work, a large amount of power in a small space. The cause of its small economy is the expenditure of a large proportion of the power in the production of local action. By remedying this defect, a very admirable machine would be produced.

We regret that a machine of the Siemens' type was not placed at our disposal, since whatever value our determinations may possess, would then have been increased by embodying data concerning a machine so widely, and so favorably known, especially as the Siemens machine employs an armature differing in construction from that of any of the machines examined, wire only being revolved, a construction, which theoretically favors economy in working.

After careful consideration of all the facts embodied in the preceding reports, the Committee has unanimously concluded that the small Brush machine, though somewhat less economical than the Gramme machine, or the large Brush machine, for the general production of light and of electrical currents, is, of the various machines experimented with, the best adapted for the purposes of the Institute, chiefly for the following reasons:

1. It is admirably adapted to the production of currents of widely varying electromotive force, and produces a good light.

2. From the mechanical details of its construction, especially at the commutators, it possesses great ease of repair to the parts subject to wear.

The Committee therefore recommends that it be selected for purchase.

The Committee desires to express its thanks to Prof. H. W. Wiley, for the loan of the Gramme machine, to the Committee of the Central High School, to the Fales & Jenks Manufacturing Co., to Mr. J. W. Sutton, to Messrs. Wm. Sellers & Co., to Messrs. W. W. Goodwin & Co., for the loan of apparatus and other favors, and to Mr. Thos. H. McCollin for his valuable services in taking the photographs from which the illustrations of the carbon points were made.

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Edwin J. Houston,
Elihu Thomson,
Theo. D. Rand,
Washington Jones,
Samuel Sartain,
J. B. Knight, *Chairman.*